Measurement Results from the Exporting Gateway Experiment

PRTN # 275

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I. Introduction

A measurement experiment was conducted on the SRI PRNET testbed to study the possible advantage of physically separating the gateway from the station. The experiment was not completed due to component failures and testbed unavailablity. In this PRTN we provide the collected results to make them available to the interested parties.

The model we used consists of a set of source PRUs and one or two destination PRUs, each PRU with an attached TIU. The experiment was run with a varying numter of source PRUs and varying traffic load. The network is fully connected.

In the next section, we detail the experiment configurations. Section III contains a chart listing the collected results. A few plots for round-trip delay vs throughput and dropped packets vs throughput are included in the Appendix.

II. Experiment Configurations

A number of experiments are detailed below. (The configurations and motivations for those experiemnts that could not be run will not be discussed here.) According to their configuration, we group the runs into four series. During these measurement runs, PRUs send their cumulative statistics (CumStats) to the measurement file every 2 minutes; TIUs sent their CumStats to the measurement file every three minutes (different rates were chosen to avoid swamping the net with simultaneous measurement packets). Each of the experiment runs was of seven minutes duration; thus allowing for four PRU CumStats and two TIU CumStats to be received from each such device during the course of each experiment run, and resulting in three PRU CumStat intervals of two minutes each, and one TIU CumStat interval of three minutes, for each such device in each run.

Thoughout this study, all runs use SPF protocol, CAP 4.7 FIFO transmission scheme, and all runs have zero-text-word packets.

Data collected from each PRU included:

- # of rx's and # of tx's over 1822 interface;
- # of radio tx's of forwarded packets;
- # of radio tx's of active ack's;
- # of correct radio rx's for intended packets;
- # of duplicate pkts rx'd;
- # of received pkts dropped for lack of hop ack;
- # of received packets discarded for lack of buffer space;
- # of alternately routed packets received.

Data collected from each TIU included:

throughput: # of packets ack'ed ETE;

mean round-trip delay for ETE ack'ed packets.

A schematic below lists the runs and the traffic input rate for each run. A symbolic configuration is shown after each series number. (The series numbers indicate the number of source and destination PRUs, e.g. "1-1".) Within each series, we label each run with a letter. A traffic source (or destination) is specified in conjunction with the TIU to which it is connected. The second traffic source of TIU#1, for example, is specified as "T1-2". The packet generation facility on the testbed generates feedback-dependent traffic. For each traffic-source / traffic-sink pair we indicate the packet generation rate by the "post-ack" delay in TIU clock ticks (60ths of a second). The "post-ack" delay specifies the interval between reception of the ETE ack of the previous packet, and the generation of a new packet. (Thus, only one packet from a given traffic source may be simultaneous outstanding in the network.)

Series 1-1 (18 runs): One source PRU and one destination PRU.

[TIU#1]-[PRU] [PRU]-[TIU#4]

	A	B	C	D	E	F
T1-1 -> T4-1	0	1	2	4	8	16

	G	H	I	J	K
T1-1 -> T4-1	0	1	2	4	8
T1-2 -> T4-2	0	1	2	4	8

	L	P	Q
T1-1 -> T4-1	0	4	8
T1-2 -> T4-2	0	4	8
T1-3 -> T4-3	0	4	8

	R	S	T	U
T1-1 -> T4-1	0	2	4	8
T1-2 -> T4-2	0	2	4	8
T1-3 -> T4-3	0	2	4	8
T1-4 -> T4-4	0	2	4	8

Series 2-1 (4 runs): Two source PRUs and one destination PRU.

[TIU#1]-[PRU] [PRU]-[TIU#4]

[TIU#2]-[PRU]

	A	B	C	D
T1-1 -> T4-1	1	2	4	16
T2-1 -> T4-2	1	2	4	16

==========

Series 3-1 (6 runs): Three source PRUs and one destination PRU.

[TIU#1]-[PRU]

[TIU#2]-[PRU] [PRU]-[TIU#4]

[TIU#3]-[PRU]

	A	B	D	F
T1-1 -> T4-1	1	2	8	32
T2-1 -> T4-2	1	2	8	32
T3-1 -> T4-2	1	2	8	32

	G	H
T1-1 -> T4-1	4	8
T1-2 -> T4-2	4	8
T2-1 -> T4-3	4	8
T3-1 -> T4-4	4	8

Series 2-2 (9 runs): Two source PRUs and two destination PRUs.

[TIU#1]-[PRU] [PRU]-[TIU#4]

[TIU#2]-[PRU] [PRU]-[TIU#5]

	A	B	C	D
T1-1 -> T4-1	1	2	4	8
T2-1 -> T5-1	1	2	4	8

	E	F	G	I	J
T1-1 -> T4-1	1	8	16	8	4
T1-2 -> T5-1	1	8	16	32	64
T2-1 -> T4-2	1	8	16	8	4
T2-2 -> T5-2	1	8	16	32	64

III. Collected Results

In the Appendix we have compiled much of the data that resulted from the above runs. For each run we list the run number, and for each PRU in that run we list the following, in terms of packets/second:

(1) receptions over the wire from the attached TIU;

(2) transmissions over the wire to the attached TIU;

(3) radio receptions that were correctly heard, and intended;

(4) transmissions of active acknowledgements;

(5) transmissions of all other packets (i.e. forwarded packets);

(6) reception of duplicate packets (packets already successfully received);

(7) a listing of the raw count of the number of:

(i) alternately-routed packets received;

(ii) packets discarded for lack of buffer space;

(iii) packets dropped for lack of an acknowledgement.

For each PRU that had an attached TIU acting as a traffic source, we give:

(1) the TIU traffic source number (corresponds with Section II);

(2) the mean round-trip delay, in milliseconds;

(3) the throughput, in packets per second.

We have also made a number of plots. Due to the feedback-dependent nature of the input traffic, the intended input rate need not correspond to the achieved throughput. Since no ETE retransmissions were observed, we use the achieved throughput (number of ETE acknowledged packets) as the standard reference

(the horizontal axis) for our plots.

For series 1-1 we have plotted round-trip (RT) delay vs throughput (Figure 1), and the total number of duplicate packets received by all PRUs vs throughput (Figure 2).

Figures 3 and 4 show similar plots for series 2-1 and series 3-1.

In Figure 5 we plot the RT delay vs throughput for the single-traffic-source-per-TIU portion of series 2-2 (i.e. runs A, B, C, and D), and also the two-traffic-sources-per-TIU portion, in which traffic is equally split between the two destinations. Figure 6 shows the associated curve for duplicate packets. Figure 7 shows curves, to be discussed in detail below, that are transformations of the curves in Figure 1.

IV. Discussion

Looking at Figure 1, we see that increasing the traffic has no effect upon the RT delay in runs A-F, indicating the absence of congestion in the network. Indeed, this is to be expected, since these runs consist of but a single traffic source, and thus only one "real" packet would be outstanding in the network at any time. It may be instructive to apportion the approximately 103 ms of RT delay among the various subsystems. Briefly, a packet in this one-hop network undergoes the following: it is

1) transmitted across the wire channel (1822 interface) at 50 KBPS from the TIU to the PRU (11+1 words for header and text);
2) processed by the PRU and placed on the (empty) radio tx queue;
3) transmitted at 100 KBPS (3+11+1+2 words for preamble, header, text, and checksum);
4) received and processed by the destination PRU; this processing results in the packet being placed on the (empty) "active ack" radio tx queue;
5) header-modified packet (3+11+0+2 words) tx'd as the active ack;
6) packet removed from active ack tx queue and processed again, and placed on the 1822 tx queue (to the destination TIU);
7) tx'd over the 1822 to the destination TIU (11+1 words);
8) processed by the destination TIU, who generates an ETE ack;
9) ETE ack tx'd over the 1822 to the PRU (11+0 words);
10) packet processed by the PRU and placed on the radio tx

queue;

11) packet tx'd at 100 KBPS (3+11+0+2 words);

12) packet rx'd at next PRU, processed, and placed on the (empty) active ack queue;

13) active ack tx'd at 100 KBPS (3+11+0+2 words);

14) packet removed from active ack queue, processed, and placed on the 1822 tx queue;

15) packet tx'd over the 1822 channel. Finished.

Based upon our oscilliscope measurements for PRU timings, and information received from SRI for TIU timings, we find that the above steps can be expected to require the following times (in msec's):

1)	1822 tx	3.84
2)	proc.	10.
3)	radio tx	2.72
4)	proc.	10.
5)	ack tx	2.56
6)	proc.	10.
7)	1822 tx	3.84
8)	TIU proc.	7.2
9)	1822 tx	3.52
10)	proc.	10.
11)	radio tx	2.56
12)	proc.	10.
13)	ack tx	2.56
14)	proc.	10.
15)	1822 tx	3.52
	Total:	~ 92 msec

This is about 10 ms shy of the measured average RT time, which is calculated using TIU clock tics (16.7 msec/tic). (Actually, it is about 13 msec shy, since the real RT time would be, on the average, half a clock tic longer than that recorded by the TIU.) One additional source of delay not mentioned above is the PRU radio hardware channel access delay, which delays

each transmission of a packet from 0 ms to approximately 6 ms (zero, one, two, or three steps of up to about 2 ms each). The four transmissions a packet undergoes would thus account for perhaps 12 of the 18 outstanding msec's.

This accounting may illustrate two points:

(1) even in a simple, one-hop, conflict-free system, a lot of work is performed to deliver and acknowledge one packet; and

(2) two-thirds of the delay results from PRU packet processing. This speaks to the importance of hardware speed, software efficiency, and protocol/header simplicity.

At a first look, the throughput (S) vs delay (D) relationship for Series 1-1 beyond runs A-F appears unfamiliar. The throughput continues to increase instead of retreating at higher input rates. The increase in RT delay, rather than accelerating, levels off. Most puzzling of all is the decrease in duplicate packets. An explanation which may be offered for this result has much to do with the effect of input feedback-dependency.

Due to the input feedback-dependency, the throughput becomes dependent upon the delay. The greater the RT delay, the longer the interval between the generation of packets, and thus the smaller the throughput. More precisely, since no ETE retransmissions is observed, the throughput achieved should be inversely proportional to the RT delay: $S \sim 1/D$. The curve in Figure 1 deviates from $S = 1/D$ for two reasons: (i) the delay plotted is RT delay, and does not include the experimenter-imposed inter-generation delay between receipt of the ETE

acknowledgement and the generation of the next packet (the post-ack-delay, PAD); and (ii) the throughput, S, is the total network throughput, rather than the per-traffic-source throughput (the feedback-dependency exists on a per-source basis).

Figure 7 shows the adjustments for these two factors. Shown are the original D vs S curves for Series 1-1. The curves with their PADs included are superimposed. And finally, these curves, with the throughput divided by the number of traffic sources, are plotted. The resulting curves conform almost perfectly to the curve $S = 1/D$.

This explanation for the effects of throughput dependency upon RT delay is not sufficient to answer the questions we have raised. In particular, what caused the number of duplicate packets to drop, and the throughput-delay curve to flatten, at the high throughput end?

It is known that, at the same traffic level, a stream of packets may move swiftly through a network, or may move slowly and suffer from repeated retransmissions and the generation of many duplicates. While the appropriate conditions for unencumbered traffic are not known for arbitrary configurations, the effects of traffic that is in some sense synchronous, and traffic in the same configuration that is asynchronous, have been noted. The conditions for synchronization are more likely to be sustained when the external environments remain relatively constant. This leads to our explanation of a synchronization effect imposed by the PRU flow control parameter TRMIDY. It is

noticed that a possible result of synchronization, a flattened throughput-delay curve and a drop in duplicate packets, occurred beginning around 12 packets/second of throughput. An apparent limit on throughput in these configurations results from the default setting of TRMIDY at 160 PRU clock ticks (about 82 msec). This parameter enforces a minimum time between the enabling of reception on the PRU's 1822 wire channel, the "station/terminal" channel. For the configurations studied (i.e. a "Ft Bragg" configuration wherein all user traffic is destined to a station/gateway PRU), all traffic must pass through that PRU and across its station/terminal 1822 channel. Return traffic must enter into the PRU over the same channel. It is at this point that the TRMIDY parameter can create a bottleneck: with its (default) value of 81.92 msec required between arriving packets on the wire channel, a maximum flow of 12.2 pps into the PRU can be accommodated, which is the same as 12.2 ETE acknowledged packets per second, acknowledged packets being the definition of throughput used herein. Because the traffic generation process is feedback-dependent, the maximum possible actual input rate (summed over all traffic generators) is thereby limited to 12.2 pps. At that operating point the interarrival time at the gateway becomes constantly equivalent to the TRMIDY setting, and the input across both wire channels (at the originating and destination TIUs' becomes very regular. Thus, we speculate that as the traffic input rate increased in Series 1-1, and as the duplicates and retransmissions increased, a point of synchrony was reached in which transmissions and/or PRU processings were no longer random or "out of synch,"

resulting in a smoother flow of traffic and subsequently a reduction in the generation of duplicates.

In the absence of more information on the timing of the detailed functions of the PRU, we are not able to explain how the interval synchronization occurs. While knowledge of the factors that contribute to an in-synch flow of traffic would be useful, it is likely that the varying nature of input traffic would limit the application of such knowledge.

One major unexplained point regards the observation of duplicate packets created in runs for single traffic source configurations (runs A-F of Series 1-1). The circumstances that lead to these duplicate packets is unclear; this is a one-hop configuration with only one traffic source and thus only one packet outstanding at a time. The timing sequence presented earlier does not appear to warrant retransmissions due to time-outs. Yet in run B, for example, during the six minute CumStat collection interval, almost 500 duplicate packets were received by the two PRUs in the course of some 3000 round-trip packets (i.e. the sending of a packet and the receipt of its ETE acknowledgement), during which there were some 3200 packet transmissions (not including transmissions of active ack's, which should not create duplicates) at the source PRU, and 3350 at the destination PRU. This means that about ten percent of packet transmissions were of duplicates (as distinct from necessary retransmissions). More precisely, it means that almost every retransmission of a packet was unnecessary and resulted in a duplicate. The question that arises is: how could an unnecessary (or even a necessary) retransmission occur

in such an empty network?

Because the traffic is feedback-dependent, a new packet is generated only after its predecessor has been ETE acknowledged (in the case of run 1-1B, 17 ms after that previous packet's ETE ack has arrived at the source TIU). Thus, one would expect that a generated packet would enter an empty network, be successfully transmitted the one hop to the destination PRU on its first attempt, be successfully active-acknowledged about ten ms later (well before the 8.2 + 10.24 ms retransmission time-out, and well after however long may be required for the source PRU to reenable radio rx after having transmitted the packet). Obviously, radio channel contention should not be a factor. Nor should channel link quality be so poor as to require retransmissions, since the two radios were connected via coaxial cable. In any case, lost or unheard active acknowledgements could not have been the source of retransmissions, since the number of active acknowledgements is almost equal to the number of packets received over the 1822 (wire) channel, indicating that additional or repeated tx's of active ack's were not necessary.

In fact, the 500 duplicates are almost completely accounted for by the number of retransmissions (excess of the number of non-ack tx's over the number of packets rx'd from the attached TIU). This implies the late reception of an active ack as the event triggering the sending of retransmissions that would result in duplicates. But, as we have seen above, in an unloaded network it does not seem possible that the tx of the active ack would be delayed beyond the 8.2 + 10.24 ms

retransmission time-out period. Thus, we seem to be left with no explanation for the duplicate packets.

(One source of packets, and thus of channel contention, that has not been mentioned is the station. Although the station does initiate the sending of control packets, its traffic is at such a low level that it does not likely account for the duplicates noted. Likewise, the measurement packets themselves, occurring at two or three minute intervals, also should not account for the duplicates.)

From the above discussion, we may note the following points:

(1) As noted on page 11, about 2/3 of the delay in one-hop configurations under unloaded conditions resulted from PRU processing. The factors that make up this processing delay (protocol complexity, header structure, software design) are thus of some significance to overall network performance.

(2) We have shown how the TRMIDY (input-control) parameter can create a bottleneck in a gateway-oriented network. In the network used for these measurements, the TRMIDY parameter combined with feedback-dependency to limit the movement of packets into the network (thereby sometimes speeding the flow of those that were allowed to enter). In a network without the one-packet-outstanding limitation, e.g. TCP, the bottleneck may result in ETE retransmissions due to timing-out at the source. This extra load on the network would tend to result in further deterioration of the network performance beyond that caused by flow-control (TRMIDY) at the gateway PRU. Thus, the value of any PRU's TRMIDY parameter needs to be selected carefully so as to avoid the creation of unintended bottlenecks.

(3) The creation of duplicate packets, apparently resulting from transmissions beyond success, seems incompatible with a one-hop, single-source, one-packet-outstanding configuration. More details about the timings of activities within a PRU and the timings of interactions between PRUs are needed to explicate these results. The Pickup Packet measurement tool would provide such data.

(4) Feedback independent traffic sources are more desirable for future experiments.

Appendix:

Collected Results

Run	PRU	rates / second: wire rx	wire tx	radio corr rx	act ack tx	non-ack tx	dups	raw: alt-rt[A] disc[C] drop[D]	traffic source: attached TIU	traffic source: mean delay	traffic source: through put
1-1A	1	8.86	8.86	18.22	8.90	9.33	.46	A-1	1-1	107.7	8.67
A	4	8.74	8.74	18.04	8.78	9.27	.53				
1-1B	1	8.36	8.36	17.33	8.41	8.92	.55	A-1	1-1	103.3	8.19
B	4	8.23	8.23	17.58	8.27	9.30	1.07				
1-1C	1	7.44	7.45	15.39	7.46	7.92	.48	A-2	1-1	102.1	7.33
C	4	7.33	7.33	15.28	7.37	7.91	.58				
1-1D	1	5.99	5.99	13.41	6.05	6.27	.40		1-1	102.0	5.90
D	4	5.93	5.93	12.24	5.98	6.39	.33				
1-1E	1	4.30	4.30	8.94	4.36	4.59	.30		1-1	102.7	4.22
E	4	4.25	4.25	8.95	4.30	4.66	.39				
1-1F	1	2.76	2.76	5.69	2.80	2.89	.13		1-1	102.4	2.70
F	4	2.74	2.74	5.68	2.78	2.90	.15				
1-1G	1	10.00	10.00	24.18	11.87	14.13	4.33	A-10	1-1	198.9	4.84
									1-2	198.5	4.84
G	4	9.86	9.86	23.76	11.73	13.86	4.16	A-29			
1-1H	1	10.14	10.14	24.18	11.74	14.01	4.29	A-3	1-1	180.0	4.93
									1-2	180.1	4.93
H	4	9.91	9.91	23.77	11.70	13.82	4.04	A-8			
1-1I	1	10.11	10.11	23.78	11.27	13.62	4.03	A-2	1-1	164.7	4.91
									1-2	165.0	4.91
I	4	9.87	9.87	23.61	11.34	13.71	4.01	A-6			
1-1J	1	9.57	9.57	22.03	9.59	12.42	3.49	A-2	1-1	140.8	4.68
									1-2	141.3	4.68
J	4	9.43	9.43	21.64	10.23	12.17	2.77				
1-1K	1	8.37	8.37	17.68	8.46	9.26	.94		1-1	109.3	4.09
									1-2	108.4	4.09
K	4	8.23	8.23	17.43	8.33	9.15	.93	A-1			
1-1L	1	11.45	11.45	25.23	15.82	13.74	3.65	A-3	1-1	262.5	3.69
									1-2	261.7	3.70
									1-3	262.4	3.70
L	4	11.15	11.15	23.56	13.21	12.37	4.77	A-11			
1-1P	1	10.71	10.71	24.72	13.10	13.96	4.08	A-2	1-1	214.3	3.49
									1-2	213.8	3.49
									1-3	213.5	3.49
P	4	10.54	10.54	23.71	12.73	13.13	3.84	A-1			
1-1Q	1	9.98	9.97	23.26	11.21	13.24	3.83	A-2	1-1	169.9	3.23
									1-2	171.0	3.23
									1-3	170.4	3.23
Q	4	9.76	9.77	23.30	11.15	13.50	3.94	A-4			
1-1R	1	12.89	12.87	26.61	14.25	13.68	2.57	A-1	1-1	310.7	3.12
									1-2	311.9	3.12
									1-3	312.5	3.11
									1-4	310.9	3.11
R	4	12.59	12.59	25.80	14.64	13.17	1.62	A-2			

Run	PRU	rates / second: wire rx	wire tx	radio corr rx	act ack tx	non-ack tx	dups	---raw--- alt-rt[A] disc[C] drop[D]	=== traffic source === atta-ched TTU	mean delay	through-put
1-1S	1	11.88	11.86	25.09	13.14	13.17	4.28	A-6	1-1	303.0	2.91
									1-2	302.9	2.91
									1-3	302.8	2.91
									1-4	305.0	2.91
S	4	11.66	11.67	24.81	15.29	13.10	2.14	A-4			
1-1T	1	11.45	11.43	25.61	13.59	14.18	4.29	A-3	1-1	287.3	2.78
									1-2	287.1	2.78
									1-3	286.8	2.78
									1-4	286.2	2.78
T	4	11.21	11.19	23.88	13.43	12.63	2.91	A-2			
1-1U	1	11.17	11.15	25.49	13.48	14.28	4.19	A-4	1-1	230.6	2.70
									1-2	232.7	2.70
									1-3	231.3	2.69
									1-4	230.9	2.69
U	4	10.91	10.91	23.67	13.12	12.77	3.28	A-2			
2-1A	1	5.11	5.10	11.56	6.31	6.44	1.34	D-1 A-2	1-1	172.7	4.97
A	2	5.01	5.00	11.38	6.12	6.36	1.37	D-4 A-2	2-1	173.2	4.98
A	4	9.94	9.94	23.66	11.04	13.70	4.96	D-5 A-23			
2-1B	1	5.17	5.15	11.41	6.28	6.23	1.09		1-1	154.4	5.11
B	2	5.08	5.07	11.37	6.22	6.28	1.22	D-4 A-2	2-1	154.1	5.11
B	4	10.06	10.06	22.91	11.13	12.83	4.08	D-4 A-11			
2-1C	1	5.26	5.25	10.96	5.48	5.69	.43	D-2	1-1	122.1	5.10
C	2	5.17	5.16	11.09	5.40	5.82	.65	D-1 A-2 C-2	1-1	122.2	5.11
C	4	10.24	10.24	21.40	10.46	11.14	.99	D-2			
2-1D	1	2.73	2.73	5.72	2.75	2.98	.24	A-2	1-1	105.7	2.67
D	2	2.71	2.71	5.97	2.82	3.11	.38	A-3	2-1	106.1	2.67
D	4	5.36	5.36	11.52	5.39	6.15	.79				

Run	PRU	rates / second: wire rx	wire tx	radio corr rx	act ack tx	non-ack tx	dups	raw: alt-rt[A] disc[C] drop[D]	traffic source: atta-ched TIU	mean delay	through-put
2-2A	1	6.49	6.49	13.21	6.64	6.79	.35		1-1	138.9	6.34
A	2	6.37	6.37	13.47	6.65	6.84	.60	A-15 D-1	2-1	138.7	6.36
A	4	6.33	6.33	13.51	6.72	6.41	.56	A-15 D-1			
A	5	6.37	6.36	13.09	6.53	3.56	.40	A-6			
2-2B	1	5.78	5.77	12.43	6.14	6.64	.96	A-2	1-1	140.3	5.60
B	2	5.69	5.69	12.54	6.11	6.61	1.08	A-20 D-2	2-1	138.8	5.63
B	4	5.59	5.59	12.67	6.28	6.71	1.16	A-15 D-2 C-1			
B	5	5.69	5.68	12.24	6.01	6.54	.96	A-6 D-1			
2-2C	1	3.53	3.53	7.70	3.75	3.97	.45	A-2	1-1	123.0	5.14
C	2	5.21	5.21	11.48	5.51	6.00	.92	A-7	2-1	124.0	5.14
C	4	5.18	5.18	10.74	5.32	5.56	.40	A-3			
C	5	5.20	5.19	10.83	5.36	5.62	.46	A-5			
2-2D	1	4.21	4.20	9.54	4.64	4.96	.75	A-24 D-2 C-5	1-1	107.4	4.11
D	2	4.15	4.15	9.15	4.39	4.76	.69	A-14 D-2	2-1	109.4	4.09
D	4	4.11	4.11	8.45	4.21	4.34	.24	A-3 D-1			
D	5	4.14	4.13	8.51	4.29	4.37	.25	A-6 D-1			
2-2E	1	5.99	5.99	14.49	8.56	8.29	2.99	A-53 D-2 C-1	1-1	313.2	2.97
									1-2	321.6	2.89
E	2	5.92	5.92	12.18	8.19	8.25	3.02	A-62	2-1	313.5	2.97
									2-2	320.4	2.92
E	4	5.94	5.94	14.36	8.14	8.41	3.23	A-39 D-1			
E	5	5.88	5.88	14.22	8.00	8.33	3.26	A-48			
2-2F	1	5.93	5.91	14.13	7.24	7.94	2.44	A-25 D-1 C-2	1-1	210.1	2.87
									1-2	208.5	2.88
F	2	5.85	5.84	13.74	6.89	7.87	2.46	A-21	2-1	206.1	2.88
									2-2	207.8	2.88
F	4	5.81	5.81	13.63	6.98	7.82	2.34	A-22			
F	5	5.84	5.82	13.60	6.89	7.77	2.26	A-8 D-1			
2-2G	1	4.96	4.96	11.32	5.47	6.17	1.38	A-15 C-2	1-1	142.3	2.42
									1-2	143.6	2.41
G	2	4.89	4.88	11.06	5.24	6.16	1.54	A-3	2-1	143.8	2.41
									2-2	142.2	2.41
G	4	4.86	4.86	11.01	5.20	6.15	1.34	A-6			
G	5	4.87	4.87	10.89	5.37	6.00	1.19	A-7			
2-2I	1	5.02	5.03	11.64	5.66	6.39	1.53	A-9 D-2 C-2	1-1	149.1	3.49
									1-2	170.6	1.42
I	2	4.98	4.98	11.00	5.45	6.01	1.16	A-3	2-1	147.8	3.50
									2-2	168.7	1.41
I	4	7.04	7.04	15.68	7.52	8.64	1.80	A-9 D-1			
I	5	2.87	2.87	6.54	3.24	3.66	.87	A-6 D-1			
2-2J	1	5.47	5.46	13.31	6.23	6.51	1.14	A-12 C-3	1-1	149.0	4.54
									1-2	191.7	0.79
J	2	5.41	5.41	11.73	5.96	6.31	1.03	A-7 D-1	2-1	149.0	4.54
									2-2	185.8	0.79
J	4	9.13	9.12	19.96	9.69	10.82	2.09	A-13			
J	5	1.64	1.63	3.75	1.97	2.10	.51				

Run	PRU	rates / second: wire rx	wire tx	radio corr rx	act ack tx	non-ack tx	dups	---raw--- alt-rt[A] disc[C] drop[D]	traffic source: atta-ched TIU	mean delay	through-put
3-1A	1	3.60	3.59	8.24	5.77	4.63	1.07	D-1 A-12	1-1	267.1	3.46
A	2	3.55	3.54	8.27	5.90	4.46	.99	D-1 A-18	2-1	266.6	3.46
A	3	3.55	3.55	8.04	5.55	4.48	.95	D-2 A-1 C-1	3-1	263.6	3.50
A	4	10.49	10.49	25.41	12.04	14.55	7.58	D-1 A-121 C-5			
3-1B	1	3.63	3.63	8.30	5.59	4.66	1.06	D-1 A-1	1-1	245.8	3.52
B	2	3.55	3.55	8.15	5.41	4.59	1.08	D-1 A-3	2-1	247.0	3.50
B	3	3.55	3.55	8.20	5.47	4.64	1.12		3-1	247.4	3.51
B	4	10.57	10.57	25.18	11.69	14.60	7.63	D-1 A-67			
3-1D	1	3.49	3.49	7.69	4.19	4.19	.71	A-4 D-1	1-1	157.9	3.38
D	2	3.43	3.43	7.54	4.09	4.10	.67	A-3	2-1	156.6	3.39
D	3	3.42	3.41	7.79	4.30	4.19	.78	A-4	3-1	156.8	3.38
D	4	10.13	10.13	23.57	11.18	13.24	4.20	A-27 D-1 C-2			
3-1F	1	1.60	1.60	3.44	1.66	1.84	.24		1-1	109.9	1.54
F	2	1.59	1.58	3.31	1.64	1.71	.12	A-2	2-1	110.3	1.55
F	3	1.59	1.59	3.60	1.72	1.83	.25	A-4	3-1	110.4	1.54
F	4	4.67	4.67	10.44	4.85	5.58	.92	A-4 C-1			
3-1G	1	5.52	5.51	12.36	8.41	6.74	1.29	A-10 D-2	1-1	304.8	2.64
									1-2	305.5	2.65
G	2	2.75	2.74	6.15	4.53	3.39	.66	A-13	2-1	297.5	2.71
G	3	2.75	2.75	6.37	4.80	3.42	.63	A-5 D-3 C-2	3-1	297.5	2.71
G	4	10.63	10.64	25.26	11.98	14.44	7.67	A-129 D-1			
3-1H	1	5.37	5.37	12.27	7.60	6.90	1.66	A-9 D-1	1-1	245.6	2.60
									1-2	245.8	2.60
H	2	2.65	2.66	6.11	4.09	3.45	.81	A-7	2-1	245.6	2.61
H	3	2.64	2.63	6.36	4.43	3.52	.86	A-6 D-2	3-1	242.0	2.62
H	4	10.38	10.38	24.79	11.73	14.14	6.97	A-96 D-1			

Figures

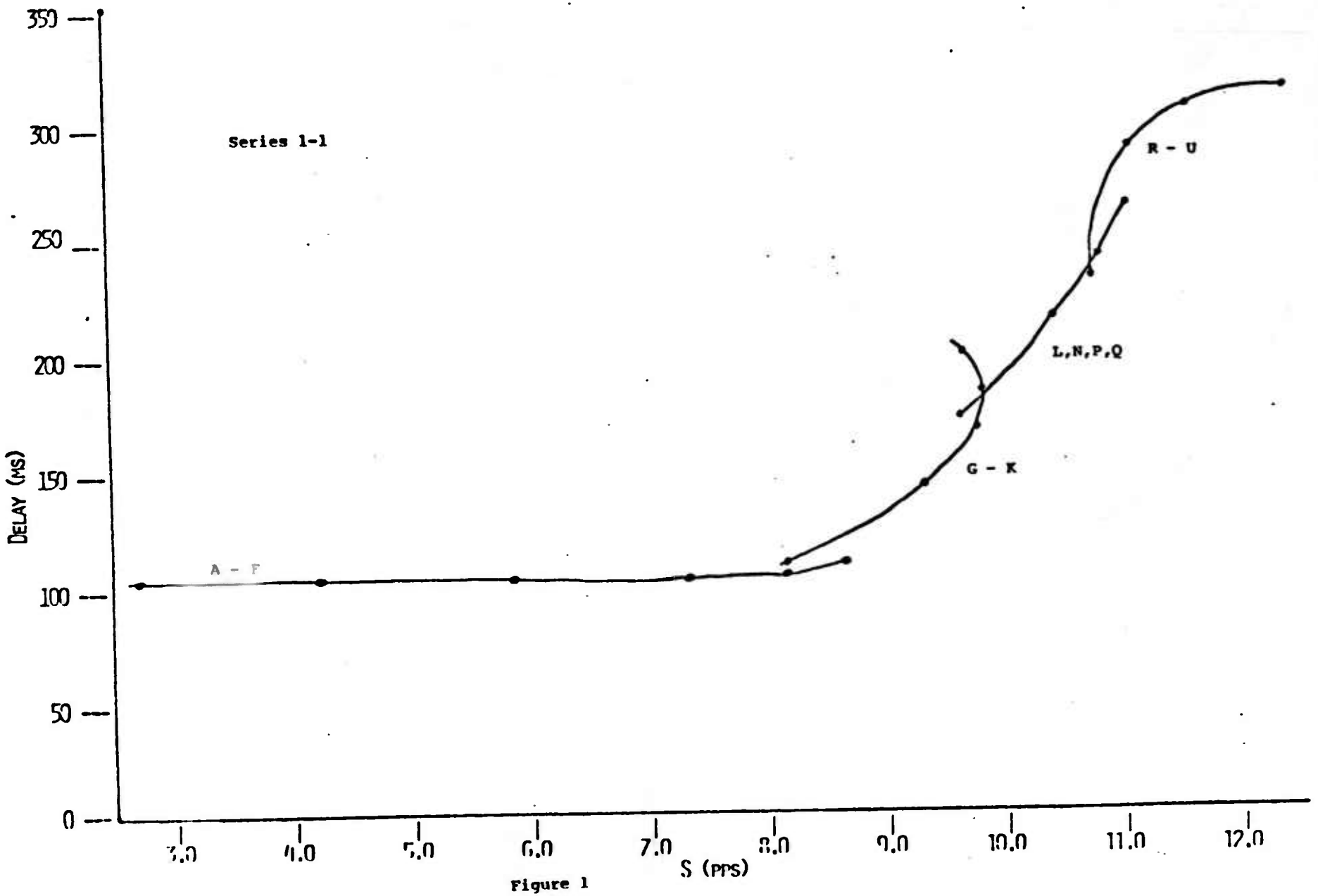
Series 1-1
DELAY (MS)
350
300
250
200
150
100
50
0
A - F
G - K
L,N,P,Q
R - U
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
S (PPS)

Figure 1

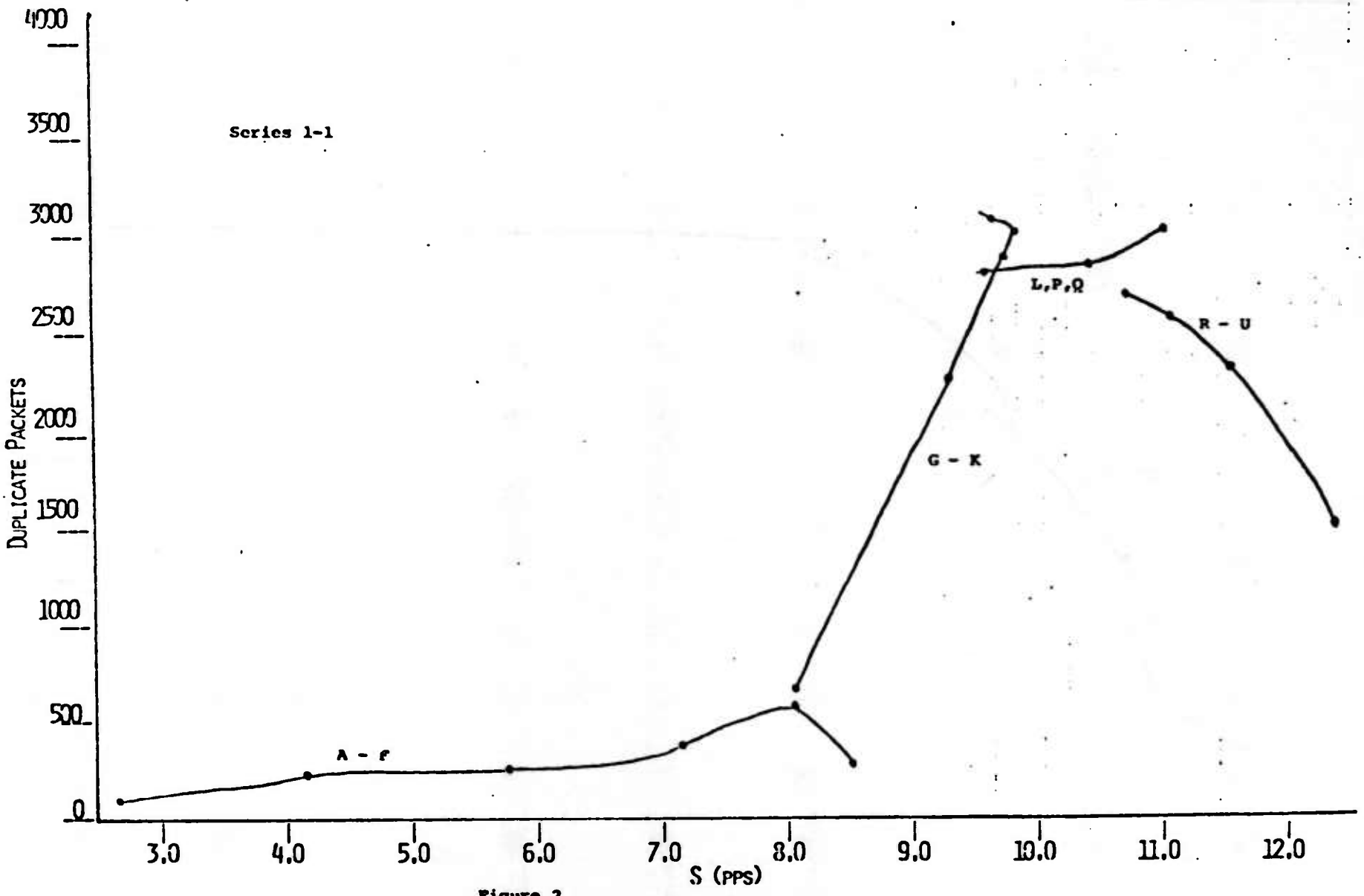
Series 1-1
DUPLICATE PACKETS
4000
3500
3000
2500
2000
1500
1000
500
0
A - F
G - K
L,P,Q
R - U
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
S (PPS)

Figure 2

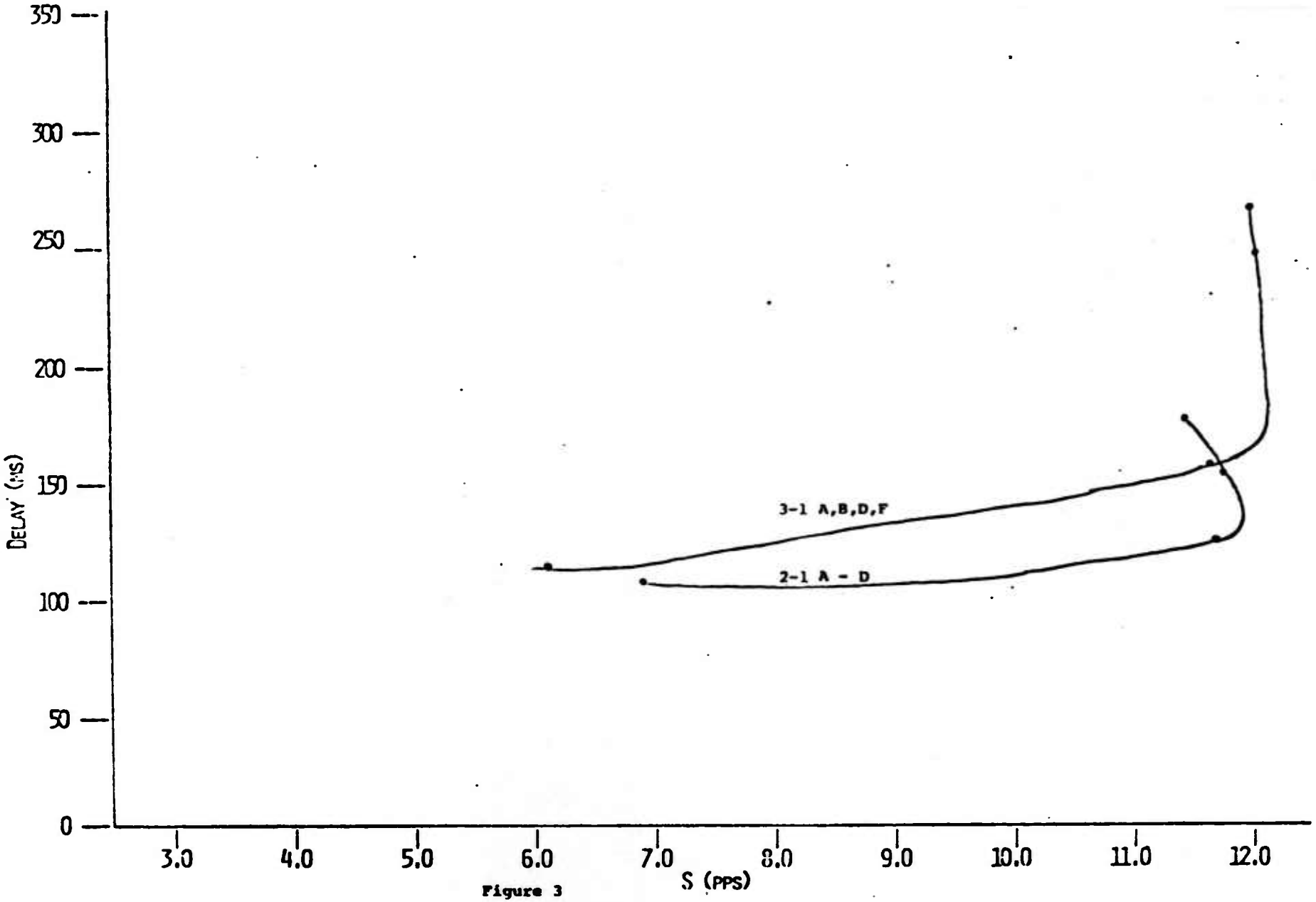
350
300
250
200
150
100
50
0
DELAY (MS)
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
S (PPS)
3-1 A,B,D,F
2-1 A - D

Figure 3

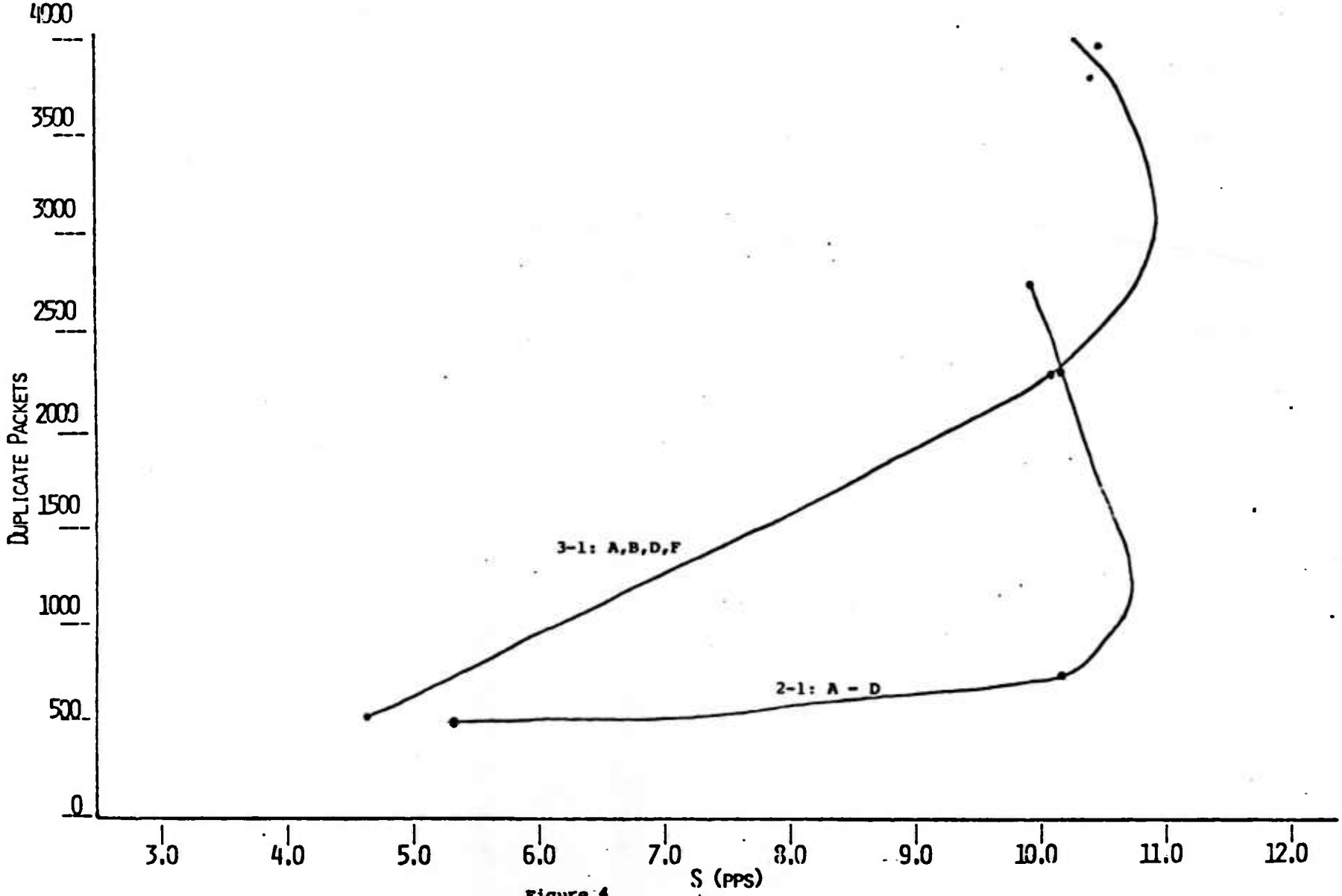
4000
3500
3000
2500
2000
1500
1000
500
0
DUPLICATE PACKETS
3-1: A,B,D,F
2-1: A - D
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
S (PPS)

Figure 4

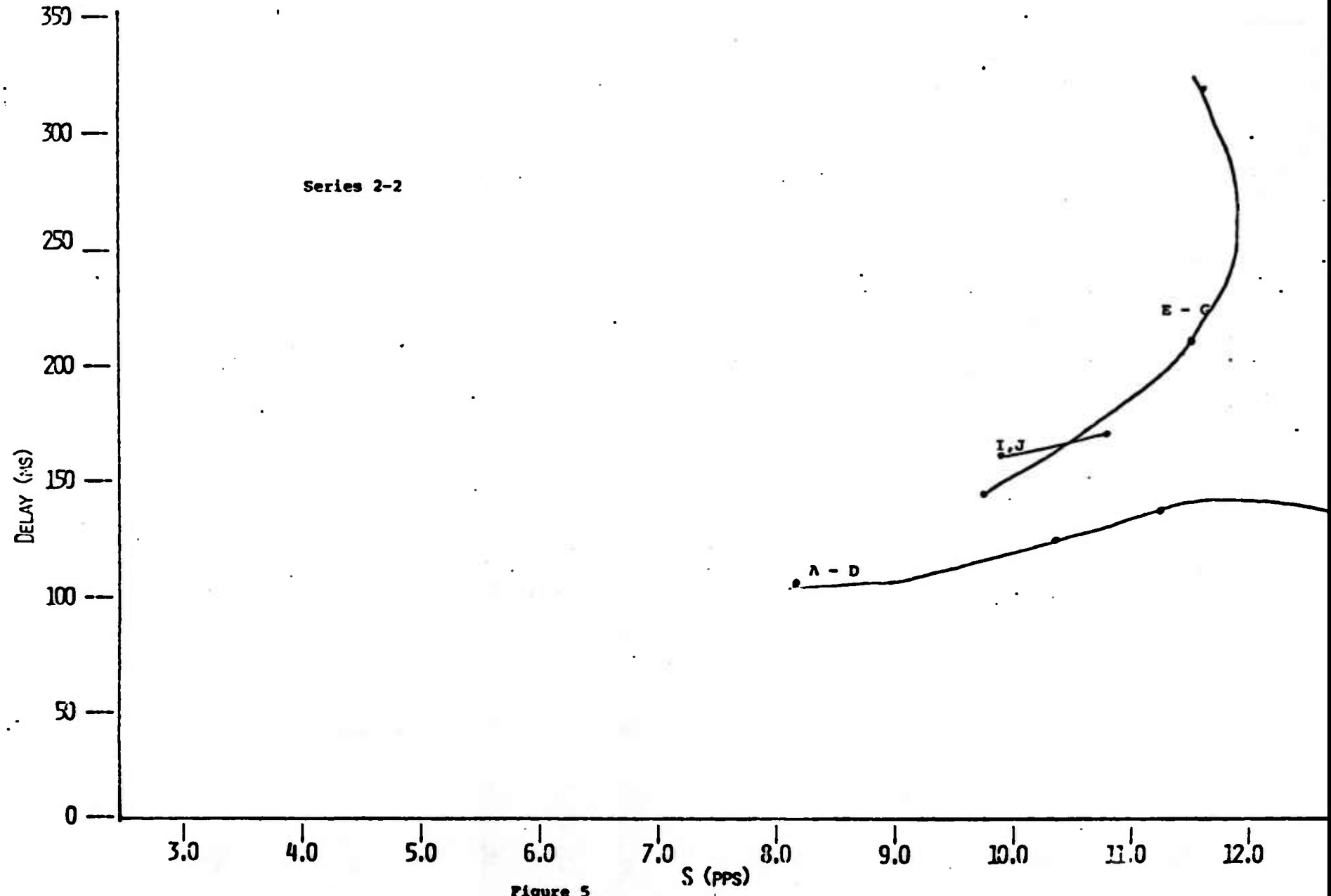
Series 2-2
350
300
250
200
150
100
50
0
DELAY (MS)
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
S (PPS)
E - G
I, J
A - D

Figure 5

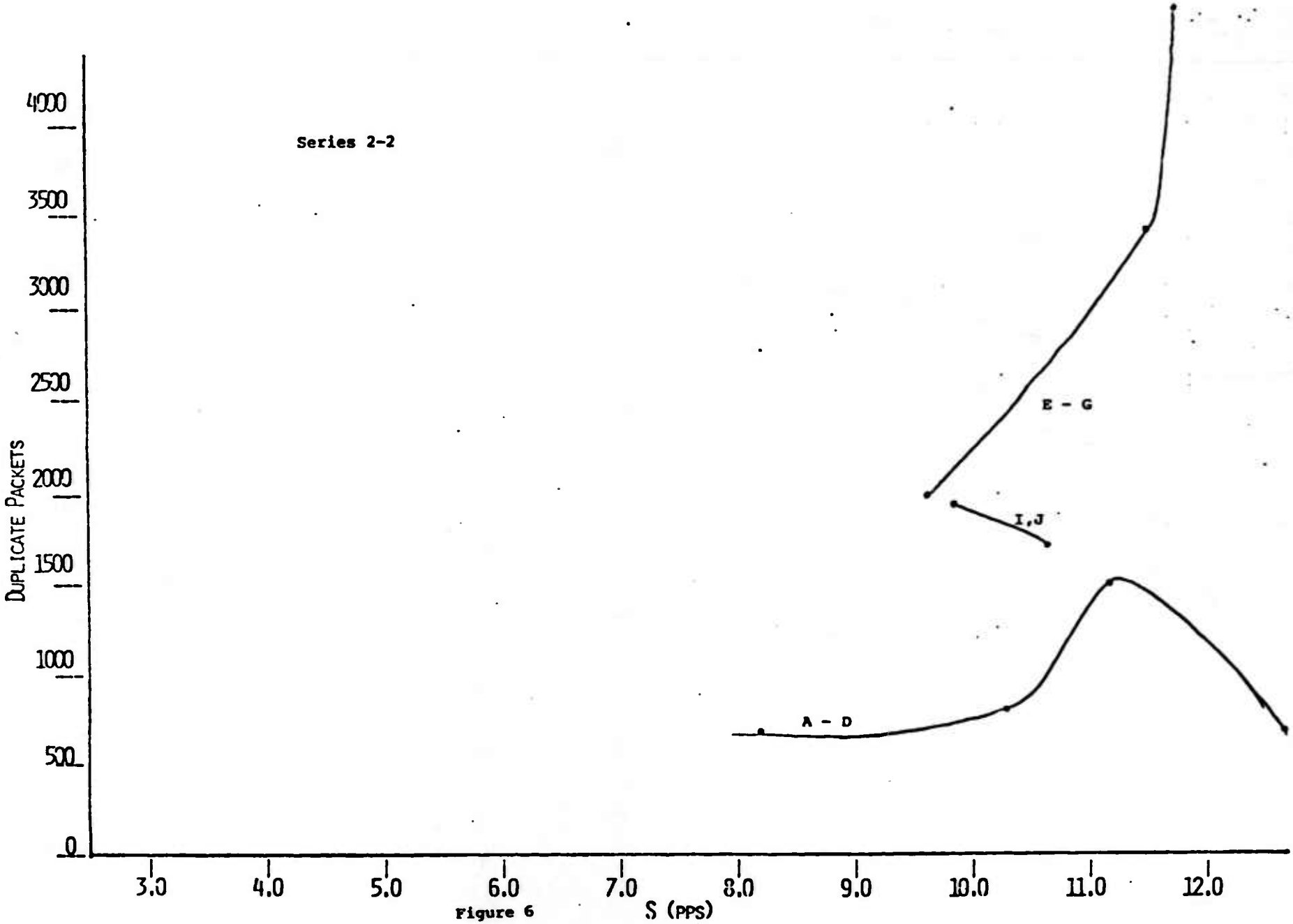
Series 2-2
4000
3500
3000
2500
2000
1500
1000
500
0
DUPLICATE PACKETS
E - G
I,J
A - D
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
S (PPS)

Figure 6

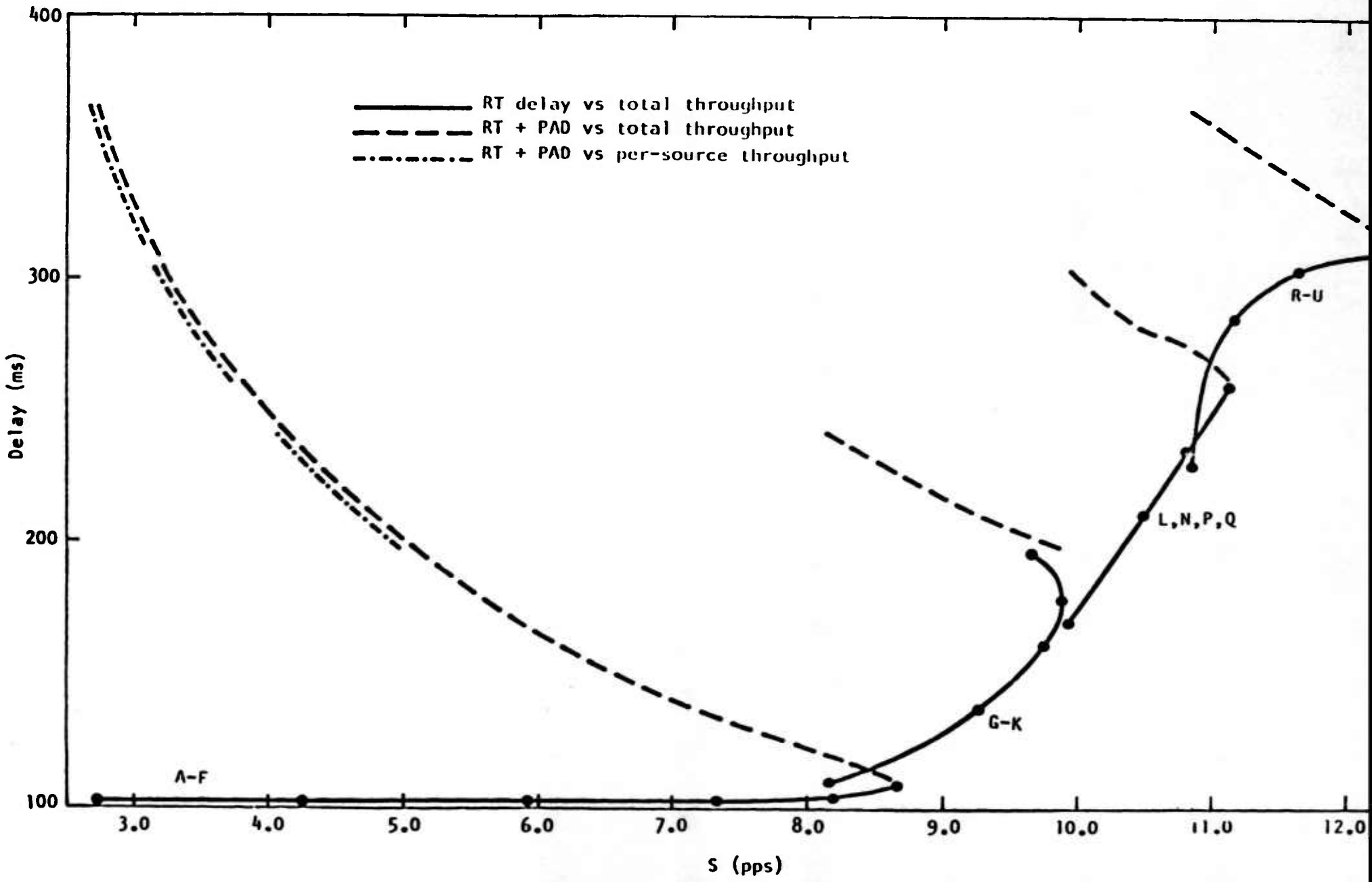
RT delay vs total throughput
RT + PAD vs total throughput
RT + PAD vs per-source throughput
400
300
200
100
Delay (ms)
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
S (pps)
A-F
G-K
L,N,P,Q
R-U

Figure 7